CO_2 OCEAN DISPOSAL RESEARCH IN HAWAII

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Background

Greenhouse gas emissions and their potential impact on global climate have been the focus of intensifying interest and debate. Carbon dioxide (CO_2) currently is the most important of these gas species due to the preponderant quantities being released into the atmosphere by anthropogenic sources–largely through the combustion of fossil fuels. During the 1992 UNCED conference in Rio de Janeiro, an agreement was reached which called for industrialized countries to stabilize their greenhouse gas emissions by the year 2000 at 1990 levels. Although the extent of implementation of related policies and technical activities has varied greatly among the signatory nations, the most recent negotiations held in Berlin in 1995 suggest a renewed commitment to the goals of the 1992 agreement. It appears, therefore, that a shift in energy policy and redirection of resources to accelerate development of technologies that limit greenhouse gas emissions may be forthcoming.

About 6 billion tons of carbon per year are released worldwide into the atmosphere as a consequence of burning fossil fuel. If stabilization of net CO_2 emissions is adopted as a policy goal in the U.S. and other developed nations, then advanced emissions control techniques for fossil fuel combustors need to be developed to supplement or to provide alternatives to options such as efficiency improvements, energy conservation, or fuel switching. To this end, a number of studies have been initiated to evaluate the feasibility of techniques to recover, reuse, and/or dispose of 'fossil' CO_2. One technique that has emerged as a primary candidate for the control of atmospheric carbon emissions involves extraction of CO_2 from flue gases, followed by liquefaction and sequestration in the deep ocean.

Removal and liquefaction of CO_2 from the effluent streams of industrial fossil fuel combustors can be accomplished utilizing existing technologies, albeit at substantial cost. The technical viability of the concept as a means to stabilize emissions therefore depends on whether long term (i.e., of the order of centuries) sequestration of the captured CO_2 from the atmosphere can be achieved. Given the limited range of reuse options, large quantities of CO_2 will need to be disposed of in an environmentally safe, and cost effective manner. Disposal in the ocean and in subterranean sites such as spent gas wells, aquifers, salt domes, and rock caverns has been considered. Several factors recommend marine disposal, the foremost being the very large capacity of the oceans to absorb and to retain CO_2. According to recent IPCC (Intergovernmental Panel on Climate Change) estimates, the deep ocean, which is unsaturated with CO_2, currently contains approximately 38,000 Gt (Gigatonne = 10^9 tonnes) of dissolved inorganic carbon (DIC). For a maximum DIC concentration of about 1.6% carbon by weight, saturation of the deep ocean would require dissolution of more than 10^7 Gt CO_2. Existing recoverable fossil fuel reserves are believed to hold between 4,000 and 7,000 Gt of carbon which, if completely oxidized, would yield no more than 2.5×10^4 Gt CO_2. In comparison, studies suggest that the CO_2 storage capacity of all the world's depleted natural gas reservoirs is only about 180 Gt, while useless (i.e., saline) aquifers can absorb an additional 320 Gt.

CO_2 Ocean Disposal Research in Hawaii

The Pacific International Center for High Technology Research (PICHTR), a private, non-profit organization established in 1983 by an Act of the Hawaii State Legislature, and the Hawaii Natural Energy Institute (HNEI) of the School of Ocean and Earth Sciences and Technology of the University of Hawaii (UH), initiated a program to study techniques to reduce CO_2 emissions from industrial fossil fuel combustors in mid-1990. Through 1993, funding for the program was provided by a grant from the Ministry of Foreign Affairs of the Government of Japan to PICHTR.

Support for the initiative currently is being received by HNEI from the Federal Energy Technology Center (FETC) of the U.S. Department of Energy (DOE), with contributions from ABB Management, Ltd. (Switzerland) and Statoil (Norway).

The PICHTR/HNEI CO_2 research program began with analyses to assess the technical and economic feasibility of CO_2 separation from fossil fuel combustors and expanded to include experimental and theoretical investigations of deep ocean CO_2 disposal and related diagnostic development. Ongoing research focuses on simulating the discharge of liquid CO_2 in the deep ocean (below 500 m). Laboratory experiments are underway to investigate CO_2 effluent jet break-up and dissolution of the resultant dispersed droplet phase. Quantitative information on these processes is critical to the development of predictive models that can assess near field environmental impacts (related to acidification of sea water) and evaluate the effectiveness of the oceanic disposal strategy in controlling atmospheric levels of CO_2.

To date, the PICHTR/HNEI study of CO_2 emissions control technology and ocean disposal have produced about 30 technical publications and have served as the basis for a 1994 Ph.D. thesis and an ongoing M.S. thesis in Mechanical Engineering at the University of Hawaii. Two international collaborative research projects recently have been initiated with the University of Bergen, Norway, and the National Institute of Materials and Chemical Research (NIMC), AIST, MITI, Japan.

Facilities

The experimental facilities comprise the principal strength of the PICHTR/HNEI CO_2 program. The High-Pressure CO_2 Mixing Facility (HCMF) located at the University of Hawaii is the only facility in the world that can reproduce the dynamics of the CO_2 injection process under conditions simulating the deep ocean. The facility has attracted worldwide interest and proposals for collaborative research.

In addition to the HCMF, the program also has access to small high-pressure optical cells and laser Raman equipment at UH to study CO_2 hydrates and dissolution phenomena. A Phase Doppler Particle Analyzer (PDPA) recently was acquired with funds from a U.S. DOE University Coal Research grant to perform measurements of CO_2 droplet size, number density, and velocity in the HCMF.

Personnel

Key technical personnel of the PICHTR/HNEI CO_2 program are S.M. Masutani (who holds joint appointments at PICHTR and UH), G.C. Nihous, currently on leave from PICHTR as a Visiting Professor at the University of Hiroshima, Japan, and C.M. Kinoshita of HNEI. Both Drs. Masutani and Nihous have been invited to participate in expert workshops on ocean storage of CO_2 organized by the IEA Greenhouse Gas R&D Programme. Dr. Nihous is a member of the associated Expert Advisory Group. Brief résumés of these individuals are provided below. H. Teng a former Graduate Research Assistant for this project, earned his Ph.D. in 1994 from UH and has been investigating CO_2 hydrate kinetics at the National Institute of Materials and Chemical Research in Tsukuba, Japan since June 1995 after being awarded a prestigious 2-year Joint STA (Science and Technology Agency)/NSF (National Science Foundation) fellowship.

Stephen M. Masutani, Ph.D. — Program Manager
Associate Researcher

B.S., University of Hawaii, 1977; M.S., Stanford University, 1980; Ph.D., Stanford University, 1985; Program Manager, PICHTR, 1997-present; Associate Researcher, HNEI, University of Hawaii, 1994-present; Owner, Combustion & Power, 1991-present; Senior Mechanical Engineer, PICHTR, 1989-1994; Cooperating Graduate Faculty, University of Hawaii, Department of Ocean

Engineering, 1995-present; Cooperating Graduate Faculty and Lecturer, University of Hawaii, Department of Mechanical Engineering, 1989-present; Visiting Scientist, Hitachi Research Laboratory, Hitachi, Ltd., 1985-1988; Specialties: combustion; turbulent transport phenomena; multiphase flow; optical and probe measurement systems; thermodynamics.

Charles M. Kinoshita, Ph.D. Research Engineer

B.S., University of Hawaii, 1972; M.S., University of Hawaii, 1974; Ph.D., University of California, Berkeley, 1980. Research Engineer, Energy Conversion Program, HNEI, University of Hawaii, 1988-present; Cooperating Graduate Faculty, University of Hawaii, Departments of Biosystems Engineering and Mechanical Engineering, 1988-present; Head, Sugar Technology and Engineering Departments, Experiment Station, Hawaiian Sugar Planters' Association, 1980-1988; Project Engineer, Engineering Department, Experiment Station, Hawaiian Sugar Planters' Association, 1974-1975. Specialties: combustion modeling; biofuels; chemical processing and kinetics; thermodynamics.

Gérard C. Nihous, Ph.D. Ocean Engineer Analyst

Ingénieur Diplômé, Ecole Centrale de Paris (France), 1979; M.S., University of California, Berkeley, 1980; Ph.D., University of California, Berkeley, 1983; Visiting Professor, Hiroshima University, Ocean Engineering Department, 1996-1997; Ocean Engineer Analyst (on leave), PICHTR, 1987-1996; Affiliate Faculty, University of Hawaii, Department of Ocean Engineering, 1993-present; Shift Supervisor, San Francisco Bay-Delta Model, 1986-1987; Ocean Engineer and Hydrodynamicist, Vega & Associates, 1983-1986; Specialties: ocean engineering; physical oceanography; fluid mechanics; applied mathematics.

Research Sponsors

The PICHTR/HNEI CO_2 research program was initiated in 1990 as part of a grant from the Ministry of Foreign Affairs of the Government of Japan to PICHTR. Ongoing research is being funded by three agencies. HNEI responded to an RFP issued by the U.S. DOE's University Coal Research Program in 1994 and was awarded a three year grant in August 1995. In 1996, two smaller grants were received from ABB (Asea Brown-Bovieri) Corporate Research of Switzerland and Statoil of Norway to expand the U.S. DOE study.

Collaborations

Since January 1996, the PICHTR/HNEI team has been collaborating with personnel from the Energy Laboratory and Department of Civil and Environmental Engineering at M.I.T. and the Department of Environmental, Earth & Atmospheric Sciences at the University of Massachusetts Lowell. This collaboration has been encouraged by the U.S. DOE who currently is supporting the M.I.T. group to conduct CO_2 ocean disposal modeling studies.

Two new international research projects were initiated in 1997. In cooperation with Dr. P.M. Haugan of the Geophysical Institute of the University of Bergen, Norway, studies have begun to develop diagnostics for planned field (at-sea) experiments of CO_2 ocean disposal. This study is being sponsored by Statoil. In addition, an investigation of a novel concept to sequester CO_2 in the ocean through the generation *in situ* of solid clathrate hydrates will be conducted in 1997-1998 with Dr. A. Yamasaki of the National Institute for Materials and Chemical Research (NIMC) in Tsukuba, Japan. NIMC is a laboratory of the Agency for Industrial Science and Technology of the Ministry of International Trade and Industry of the Government of Japan. MITI has supported a major research initiative on CO_2 separation and disposal since the late 1980's.

Future Activities

Laboratory and modeling studies of CO_2 ocean disposal have advanced the concept to a point where field tests are warranted. Such tests represent a major multi-year endeavor that would most likely enlist the participation of researchers from the U.S., Japan, and Europe and be funded internationally under Task Force 7 of the Climate Technology Initiative (CTI). Drs. Nihous and Masutani have been working with the M.I.T. group who were commissioned by U.S. DOE to provide recommendations for a CO_2 ocean disposal field test program.

Articles and Presentations

The following list of publications and technical meeting papers were produced as result of research on CO_2 emissions control conducted by the PICHTR/HNEI team.

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